Artificial woodland degradation in semi-arid agro-pastoral transitional area: conceptual model and status assessment

YANG Xiao-hui[1], CI Long-jun[1*], ZHANG Ke-bin[2]

[1] *Research Institute of Forestry, Chinese Academy of Forestry, Key Laboratory of Tree Breeding and Cultivation, State Forestry Administration, Beijing 10091, P. R. China*

[2] *College of Soil and Water Conservation, Beijing Forestry University, Beijing, 100083, P. R. China*

Abstract: Planting trees was used as one of cost-effective measures for desertification control in arid and semi-arid areas of China. Woodland degradation, however, is becoming an inevitable issue in these areas. In this paper, a typical county, Ejin Holo County, Inner Mongolia, China was selected for its assessment of artificial woodland degradation. A conceptual model for woodland degradation was delineated qualitatively based on field sampling survey, and four model-based indicators as humidity index (HI), vegetation index (NDVI), soil type (ST) and soil erosion modulus (EM) were screened out and used to a GIS-based method for artificial woodland degradation assessment in this semi-arid agro-pastoral transitional area. All the indicator layers were overlaid and desertification assessed using simplified equation with equal weights for each indicators. The assessment results showed that in 336.09 km^2 of total woodland area, 311.35 km^2 woodland were under degradation, and the area for slight, medium, severe degradation was 78.97, 119.73 and 112.65 km^2, respectively. It was suggested that much attention should be paid on woodland improvement and plant species selection, especially shrub species, before revegetation in similar areas.

Keywords: Artificial woodland; Degradation model; GIS; Degradation assessment, Semi-arid area

ClC number: S728.2 ; S718.551.2 **Document code**: A **Article ID**: 1007-662X(2006)03-0247-05

Introduction

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities (INCD 1994). Human activities, such as overgrazing, over-cultivation, unwise irrigation activities, deforestation, and civil and industrial activities, could result in desertification (Thomas & Middleton 1994). Deforestation originated from human immoderate need for timber, firewood and land resources, whereas afforestation and reforestation were considered as one of cost-effective measures for desertification control and woodland was also considered as non-desertification area in desertification assessment (CCICCD 1997). Afforestation and reforestation activities were conducted not only in the areas where natural forest or woodland had been cleared out, but in those areas where no forest or woodland existed historically at all, even the former paid less attention to the origin structure of cleared natural forest, fixed plantation density was determined for implementing convenience.

Nowadays, woodland degradation is an unavoidable phenomenon in arid and semi-arid areas of China and become being accepted by the environmentalists (CCICCD 1997). Generally, there are several types of woodland degradation in desertification-prone area, *i.e.* (1) natural or artificial woodland along the rivers declined or withered up due to natural change of river courses or the over-interception and over-use of water resources in the upper or middle reaches, such as *Populus euphratica* woodland in lower reach of Tarim River (*e.g.* Ji *et al.* 2001); (2) too high density and non-scientific tree species selection lead to the over-consumption of precious water resources and long-term serious water deficit in artificial woodland, growth condition of the whole stand is very poor and many “dwarf trees” appear (Yang 1996; Wang *et al.* 2001), the whole woodland ecosystem is under vicious cycle, and plant diversity and vegetation coverage reduce drastically.

This paper, based on field sampling survey, developed a conceptual model for woodland degradation in Ejin Holo County, Inner Mongolia, and assessed its woodland degradation status in 2002 integrating GIS with remote sensing. Some suggestions were given to solve the dilemma between degraded woodland improvement and reforestation in future.

Materials and methods

Study site

Ejin Holo County is located at longitude 108°58′−110°25′ E and latitude 38°56′−39°49′ N, the middle of Ordos Plateau and northern edge of the Mu Us sandland. Administratively it belongs to Ekizhao Perfecture, Inner Mongolia. The total area is 5 956 km^2 (Fig. 1). Climatologically, it is temperate continent type. Annua mean precipitation is 352.9 mm, and 70% of total precipitation concentrates in the summer (from July to September). Annual average temperature is 6.39°C, with -31.4°C minimum in January and 36.6°C maximum in July, Frost-free days is 127−140 days. Strong wind period annually averages 26 days and annual average period of dust storms is 17 days. Geo-morphologically, the study area consists of sand-covered or loess-covered hilly and gully plateau sub-area, sandy ridge-land-floodland plateau sub-area and sandland sub-area (a part of the Mu Us Sandland) (ISTLP-CAS 1991).

Foundation project: This paper is funded by National Natural Science Fund (30171205) and National Tenth-year-plan Key Sci&tech Project (2005BA517A04)

Biography: YANG Xiao-hui (1968-), male, PH.D. in landscape ecology and desertification combating, Research Institute of Forestry, Chinese Academy of Forestry, Beijing 10091, P.R. China E-mail: yangxh@forestry.ac.cn

*Corresponding author

Received date: 2006-01-20

Accepted date: 2006-07-06

Responsible editor: Chai Ruihai

Ejin Holo County has abundant herbaceous species. However due to long-term human destruction, zonal vegetation such as *stipa* spp. dominated communities had been replaced by azonal psammophytic vegatation such as *Artemisia spp.* which occupies for about 60 percent of vegetation cover in study area. In bare sandland and sand-covered hill areas, *Artemisia ordosica* is dominant species. Eroded hill and a part of sand-covered hill landscapes are dominated by *Caragana microphylla* and *Caragana intermedia*. In addition, sub-mesic bunchgrass, meadow plants and bogged salix bushes grow in some lower-lying areas such as wadies and interdunes. Even psammophytic communities also have secondary features to the extent due to unwise use.

Fig. 1 Location map of Ordos Plateau and study site

Methods

A sampled field investigation was conducted for artificial woodland degradation in 1998. According to the distribution map of woodland in Ejin Holo County provided by local forestry department, 86 woodland patches were sampled, which cover all the geomorphological types and soil types. Parameters were measured in-situ, *i.e.* tree species, tree canopy coverage, understory coverage, tree height, DBH, stand density, root nudeness and soil type. Based on the ground truth for woodland condition, a conceptual model for woodland degradation was delineated qualitatively, and four indictors were screened out to assess woodland degradation.

Woodland distribution map (1:10000) in 1997, soil type map (1: 10000) in 1996 and soil erosion map (1: 10000) in 1999 were acquired from local professional departments. Monthly precipitation and temperature from 1959–2002 in Ejin Holo County and its surrounding counties were collected and potential evapo-transpiration (PET) were calculated with Thornthwaite method (Thornthwaite 1948). To ensure the accuracy of the calculated humidity index, more meteorological data from 1959 to 1980 were also collected in some temporary meteorological stations in the study area. Co-kriging method under ArcGIS 8.0 software was used to interpolate with 15 m×15 m grid size. Enhanced Thematic Mapper Plus (ETM+) images in August, 2002 were selected, and normalized difference vegetation index (NDVI) value acquired from each pixel to reflect vegetation cover. The NDVI values for each woodland patch were averaged from the each pixel NDVI data (Fig.2).

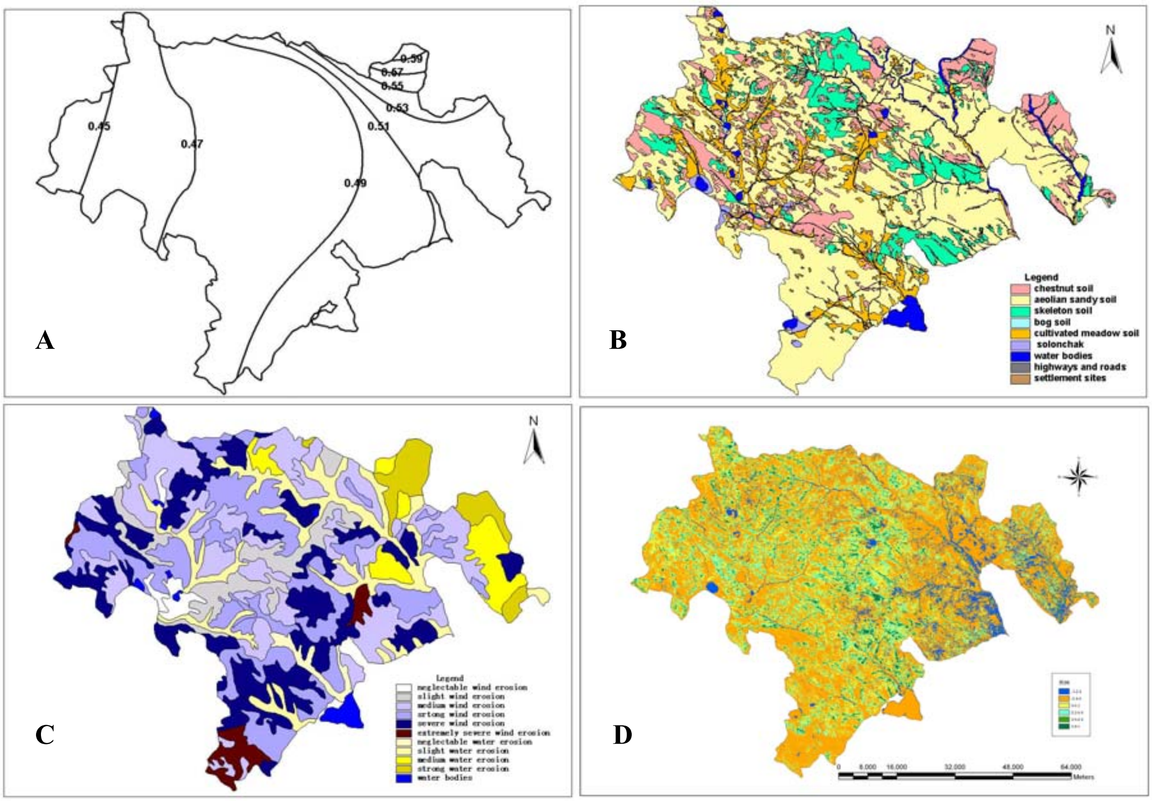

Fig. 2 The thematic maps of four assessment factors used in Ejin Holo County

A--- Humid index, B--- soil type, C--- soil erosion modulus, and D--- NDVI

The Desertification Assessment is a combination of the four indicators described above, with equal importance being at-

tached to each indicator, as follows:

$$DA = HI + NDVI + ST + EM$$

where, *HI* is the humidity index, *NDVI* the normalized difference vegetation index, *ST* the soil type, and *EM* the soil erosion modulus.

The digitized data layers for each indicator were scaled, where the values from one to four represent degraded levels from non-degradation to severe degradation for each indicator. Values for four indicator layers were overlaid and summed to create a new single layer, resulting in a theoretical range of degraded values from 4 to 20. These values were rescaled from one to four to produce the woodland degradation assessment map (Wade *et al*. 1994).

Results and discussion

A self-augmenting woodland degradation model was generalized in this study. Woodland ecosystem in semi-arid agro-pastoral transitional area often consists of three component layers, *i.e.* wood layer, understorey layer and soil layer. Usually, trees were planted in the wasteland with sparse or dense natural vegetation. During afforestation, a part of natural vegetation was cleared out, and with the tree individuals growth, the left understory coverage began to decrease due to resources competition, especially water (step 1). Soil erosion increases caused by lessening understory, wind corridor effects may increase wind velocity within stand, wind erosion was then accelerated in winter and spring, in summer, raindrops fall to the soil surface directly from or through canopy to less vegetation-covered ground, serious splash erosion occurs (step 2). Alternative activities of water erosion and wind erosion result in serious soil degradation, and growth conditions of tree individuals and understorey vegetation deteriorated, roots of some trees become to be exposed partially due to surface soil deflation (step 3). Contrarily, wood layer degradation increase the potential risk of soil erosion (step 4), nutrient poorness limited understorey growth and re-colonization of some exotic plant species (step 5). Understorey degradation may result in wood layer degradation due to less ground cover (step 6), and wood layer degradation may make trouble in recolonization and growth of some shade-tolerant plant species (step 7). This self-enhanced feedback mechanism is indeed the main cause of woodland ecosystem degradation (Fig. 3).

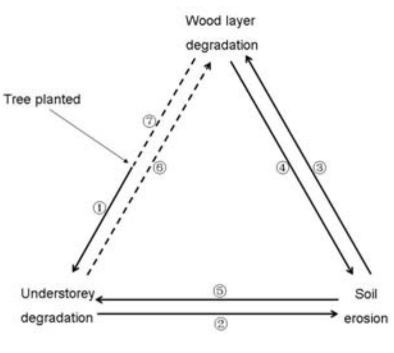

Fig.3 A conceptual model of self-augmenting feedback mechanism of artificial woodland degradation
(Each feedback step is described in explainable text, some uncertain relationships are demonstrated with dotted lines)

The assessment results showed that in 336.09 km^2 of total woodland area in the study site, 311.35 km^2 woodland are under degradation, accounting for 92.64 % of the whole woodland area or 5.23 % of the whole study area. The area of slight, medium, severe degradation are 78.97, 119.73 and 112.65 km^2, accounting for 23.50%, 35.62% and 33.52% of degraded woodland area, respectively, and only 7.36% of woodland is undegraded (Fig. 4).

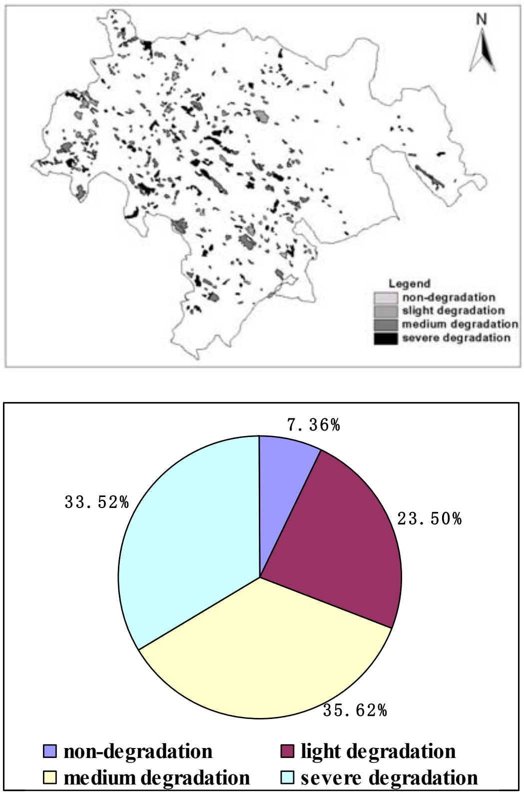

Fig. 4 Assessment map of degraded woodland in study site

Implications and conclusion

Historically, the majority of Ordos Plateau was covered by luxuriant natural forest, which was confirmed by abundant collieries in this region. It was recorded that in Qin Dynasty, the forest coverage rate were more than 50%. Slash-and-burning was started in Han Dynasty. According to statistics in the early stage of establishment of the P. R. China, the natural forest area in Ejin Holo County was less than 80 hm^2, with a forest cover rate of 0.21%, and only 10000 trees survived and distributed around temples, channels, lowland and settlements (CCYHBC 2002; Mao *et al*. 2005). Afforestation and reforestation activities had been undertaken actively since the 1950s. Until to the end of 1992, the total woodland area had reached 51405 hm^2, in which, stand area with 0.4 canopy cover was 29142 hm^2, accounting for 56.7%, stand area with 0.5 canopy cover was 11485 hm^2, accounting for 22.3%, stand area with more than 0.5 canopy cover 10778 hm^2, accounting for 21%. The results of landuse change showed that the woodland area increased by 39.75% from 1977 (239.50 km^2) to 1998 (334.69 km^2), but decreased by 3.62% from 1987 (347.24 km^2) to 1998 (334.69 km^2). Artificial woodland degradation has attracted much attention from local professional departments. The traditional afforestation using trees for soil erosion control should be changed to shrub affforestation decidedly (Yang *et al.* 2005a). It was well-known that Ordos

Plateau was a natural shrub kingdom (West 1983), shrubland was disturbance-induced, relatively stable succession stage, and considered as an optimal land use type in semi-arid area of China (Zhang 1994; Yang *et al*. 2005b).

As for degraded woodland, some improvement measures should be applied correspondingly, and some shade- and drought-tolerant shrub or grass species can be planted in woodland in order to form a savanna-like community or landscape. For severe degraded woodland, as understorey restoration seems to be impossible with anthropogenic improvement due to shortage of water and nutrient within soil, some abiotic measures to control soil erosion should be used to reduce the accelerating trend of degradation, and some ancillary revegetation means can be adapted simultaneously.

Acknowledgements

We thank professor Ding Guodong for his warm-hearted help during the data collection, and thanks are extended to Prof. Zhang Fengrong and Prof. Wang Lixin for their assistance in cartography.

References

CCICCD (Chinese Committee for Implementing UN Convention to Combat Desertiffication).1997. China country paper to combat desertification [M]. Beijing: China Forestry Publishing House, pp30–31.

CCYHBC (Compiling Committee of Yijin Holo Banner Chronicle). 2002. Yijin Holo Banner Chronicle [M]. Huhhot: Inner Mongolia People's Press, pp178–181 (in Chinese).

INCD. 1994. International Convention to Combat Desertification [M]. New York: United Nations General Assembly, pp1-2.

ISSTLP-CAS (Integrated Science Survey Team of Loess Plateau, Chinese Academy of Sciences). 1991. Exploitation of natural resources and desertification control in Ejin Holo County, Inner Mongolia [M]. Beijing: Science Press, pp8-10 (in Chinese).

Ji Fang, Ma Yingjie, Fan Zili. 2001. Soil water regime in Populus euphratica forest on the Tarim River alluvial plain [J]. Acta Phytoecologica Sinica, **25** (1): 17–21. (in Chinese)

Mao Lei, Yu Chuntang, Yang Xiaohui. 2005. Causal analysis of desertification in semi-arid agro-pastoral ecotone of China: A case study in Ejin Holo County, Inner Mongolia[J]. Chinese Forestry Science and Technology, **4**(3):11-21.

Thomas, D.S.G., Middleton, N.J. 1994. Desertification: exploding the myth [M]. Chichester: John Wiley&Sons, pp103-110.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate [J]. Geographical Review, **38:** 55-94.

Wade, T.G., Wickham, J.D., Kepner, W.G. 1994. Using GIS and a graphical user interface to model land degradation [J], Geo Info Systems, **2:**38–42.

Wang Li, Shao Ming An., Hou Qing Chun, *et al*. 2001. The analysis to dried soil layer of artificial *Robinnia pseudoscacia* forestry land in the Yan'an experimental area [J]. Acta Bot. Boreal. –Occident. Sin., **21**: 101–106. (in Chinese)

West, N.E (ed). 1983. Temperate deserts and semi-deserts [M]. Amsterdam: Elsevier Scientific Publishing Company, pp226-228. (in Chinese)

Yang Weixi.. 1996. The preliminary discussion on soil desiccation of artificial vegetation in the northern regions of China [J]. Scientia Silvae Sinicae. **32**:78-85. (in Chinese).

Yang Xiaohui, Zhang Kebin, Ci Longjun. 2005a. Tempo-spatial change of landscape pattern in semi-arid agro-pastoral transition area in recent 20 years—a case study in Ejin Holo County, Inner Mongolia [J]**.** Journal of Beijing Forestry University. **27**(5): 81-86. (in Chinese).

Yang Xiaohui, Zhang Kebin, Jia Baoquan. Ci Longjun. 2005b. Desertification assessment in China: An overview[J]. Journal of Arid Environments, **63**:517-531.

Zhang Xin Shi. 1994. Principles and optimal models for development of Maowusu sandy grassland [J]. Acta Phytoecologica Sinica, **18**:1-16. (in Chinese)